An Advanced Fuel Filter

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Develop An Innovative High Performance And High Efficiency Membrane Fuel Filter To Be Used For Diesel Fuel Engines

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Objective

Develop An Innovative High Performance And High Efficiency Membrane Fuel Filter To Be Used For Diesel Fuel Engines

Challenges In Diesel Fuel Filtration

Higher levels of contaminants (dust, fungus and bacteria, asphalt, and water) present in diesel fuel cause:

- **Filter medium surface clogging by particles.**
- **Lower water removal efficiency once the fibers. of the filter medium are coated with dirt.**
- **Frequent replacement of fuel filter**
- **Engine wear**

Better Fuel Filtration Required for Diesel Engines

Case Study on Railroad Engine By Farr and Southwest Research Institute Showing:

- Typically 10 mg/liter dirt in diesel fuel after filtration.
- A 3000 hp diesel engine burns 3,500,000 pounds of fuel per year, meaning that 35 pounds of dirt go into the engine.
- 0.3 grams per hour of 5 micron test dust fed into the engine increased engine wear rate 1,200% over the base.
- Engine ($60,000) needs to be replaced every three years due to the engine wear.

Better Fuel Filtration Required for Diesel Engines

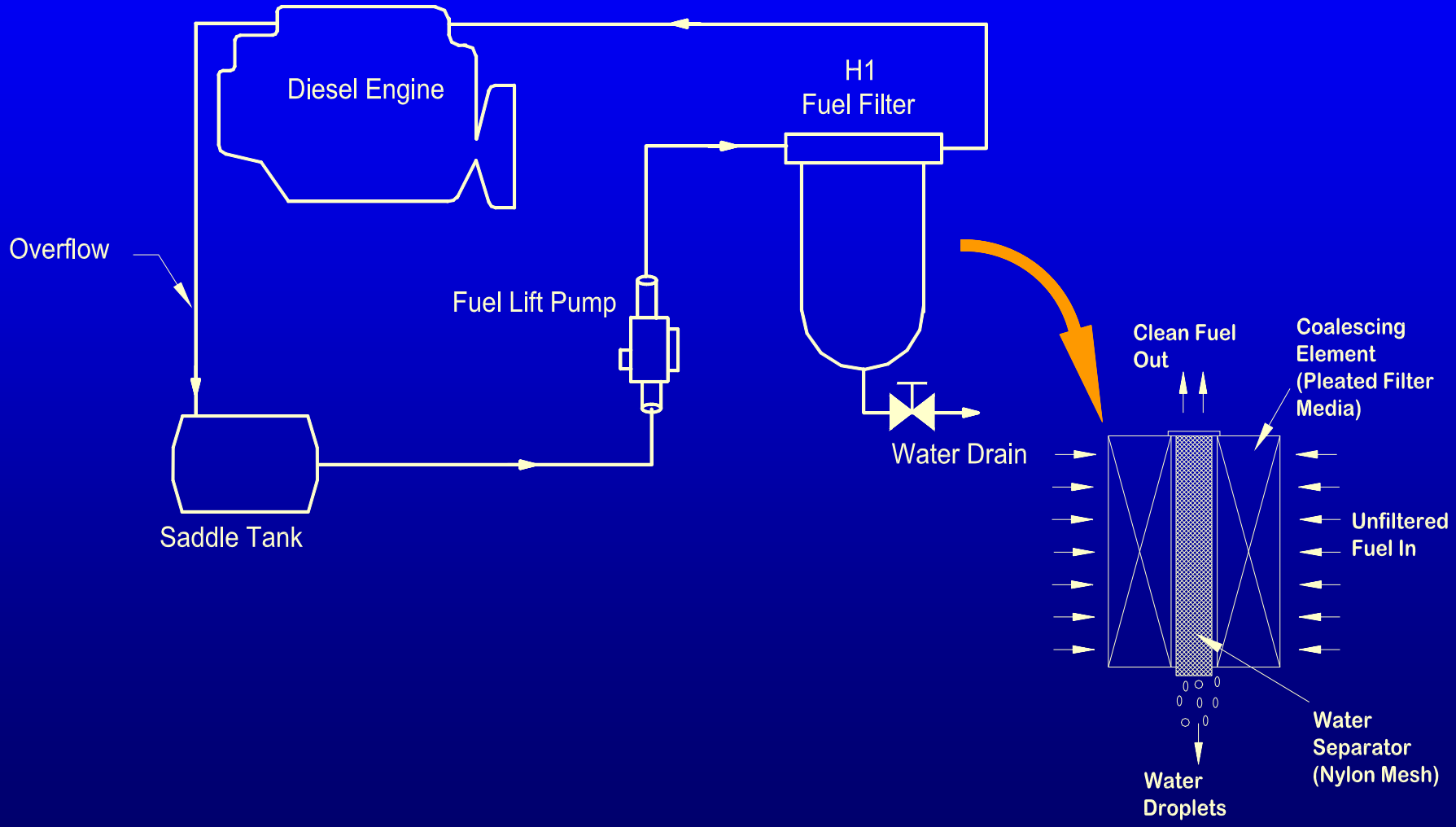
Case Study on Class 8 Truck Engine By Donaldson Company Showing:

- High efficiency fuel filter can reduce fuel injector wear by at least a factor of 2.
- Fuel filter ratings of less than 5 micron (absolute) greatly contribute to engine injector wear reduction.

Current Diesel Fuel Filtration Technologies

1. **Coalescing Filter**
   - Low cost
   - Short service life
   - Low water/debris removal efficiency
2. **Centrifugal Separator**
   - Very high cost
   - Very high maintenance cost
   - Low water/debris removal efficiency

Coalescing Fuel Filter Design and Setup



Advanced Membrane Fuel Filter

- Water-selective membrane.
- Cross-flow filtration.
- Spiral-wound membrane element.
- Replacing the conventional centrifugal separator and coalescing fuel filter.
- Designed to be retrofittable to existing military and commercial fuel filter housings.

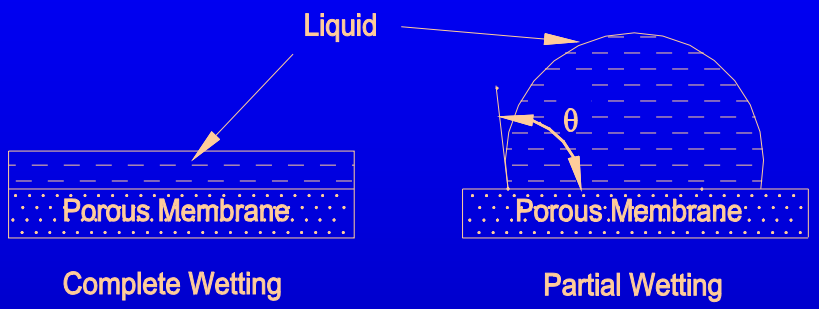
Theory of Water-Selective Membrane

The water separation mechanism of a MF membrane in the fuel filtration process can be described by the Laplace equation:

$$\Delta P = -2 \gamma \cos\theta / r$$

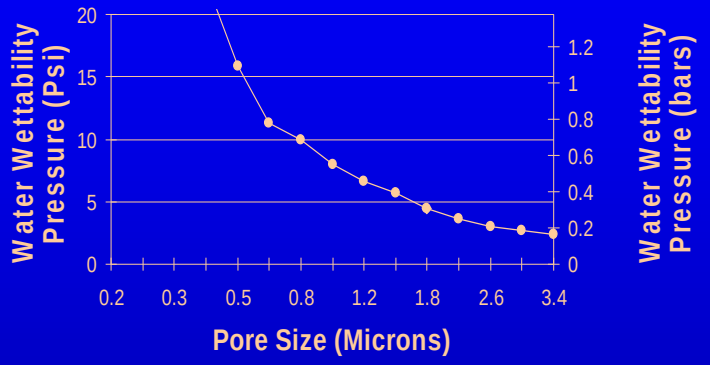
Where ΔP is liquid entry pressure, γ is liquid surface tension, θ is the liquid contact angle or the surface energy of the MF membrane, and r is the membrane pore size.

Theory of Water-Selective Membrane



Liquid Drop on Porous Surface

Showing the Contact Angle θ

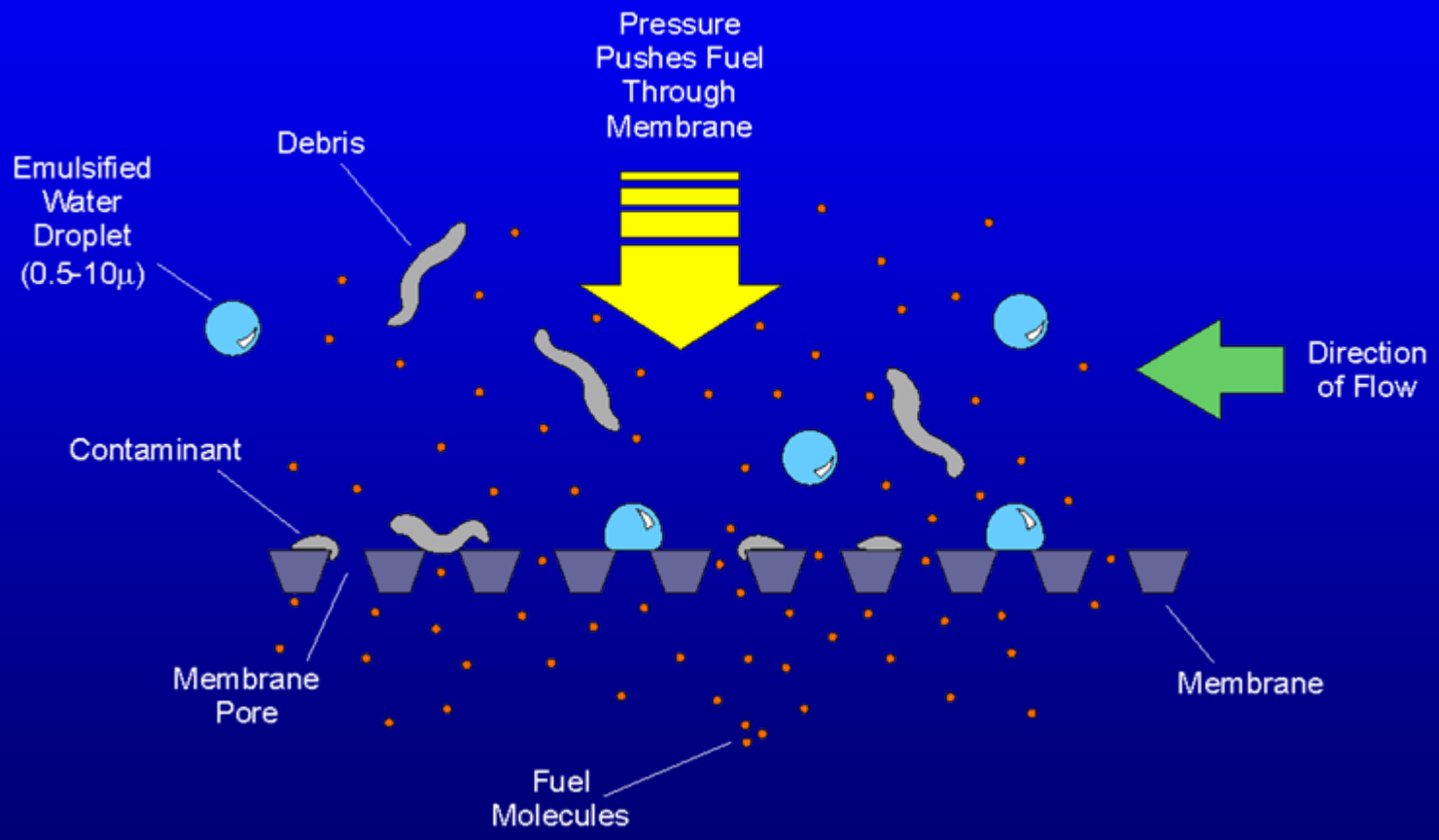


Required Entry Pressure for Water through a Hydrophobic Membrane

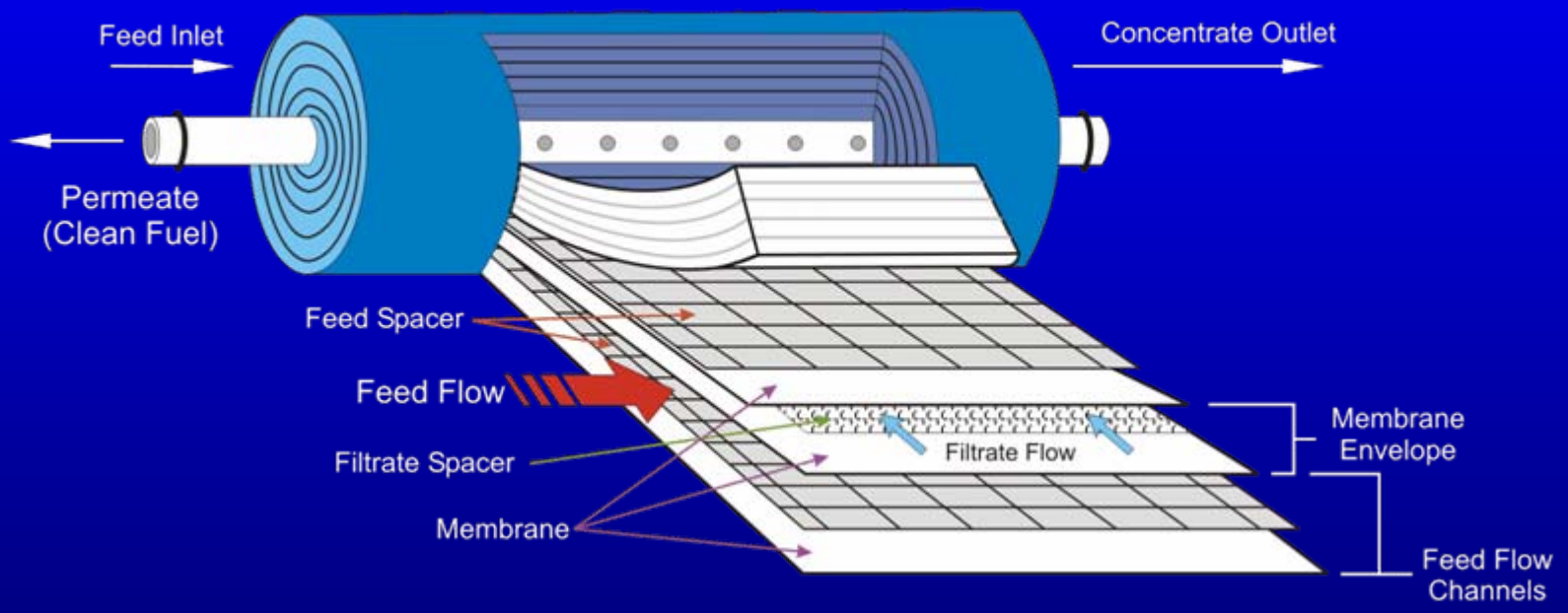
For fuel, $\theta < 90°$ and $\cos\theta > 0°$, thus ΔP is negative. This means that the fuel will penetrate through the MF membrane without applying entry pressure.

For water. $\theta > 90°$ and $\cos\theta < 0°$, thus ΔP is positive. This suggests that water can not penetrate through the membrane pores unless a certain entry pressure is applied on the membrane surface.

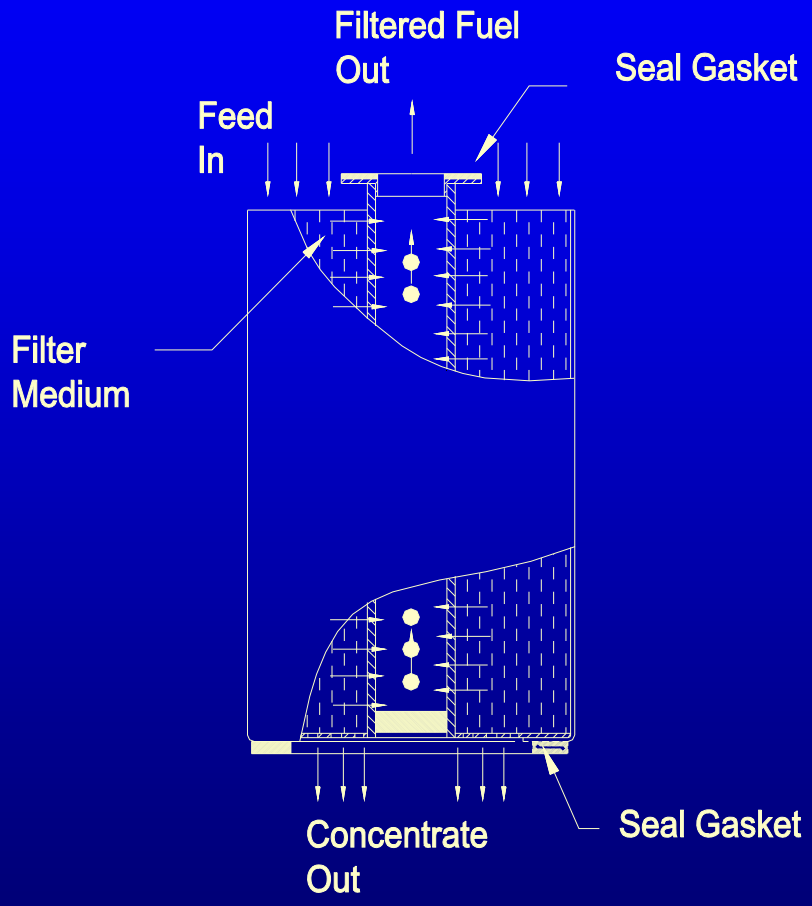
Cross-Flow Filtration



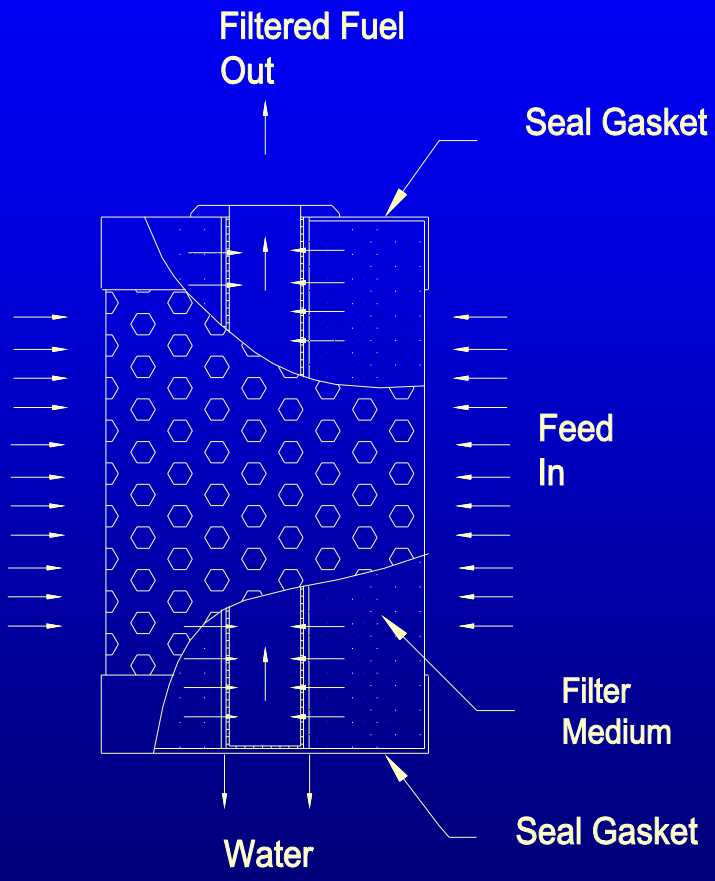
Spiral-Wound Membrane Filter Design Principal



Spiral-Wound Membrane Fuel Filter Element Design

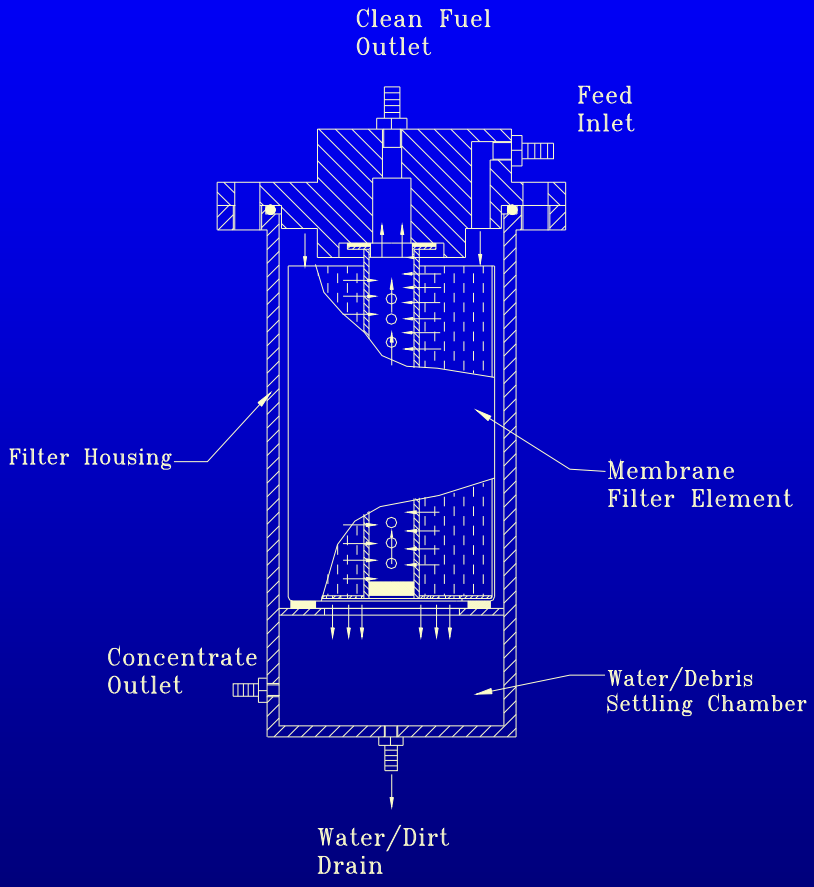


Membrane Fuel Filter Element



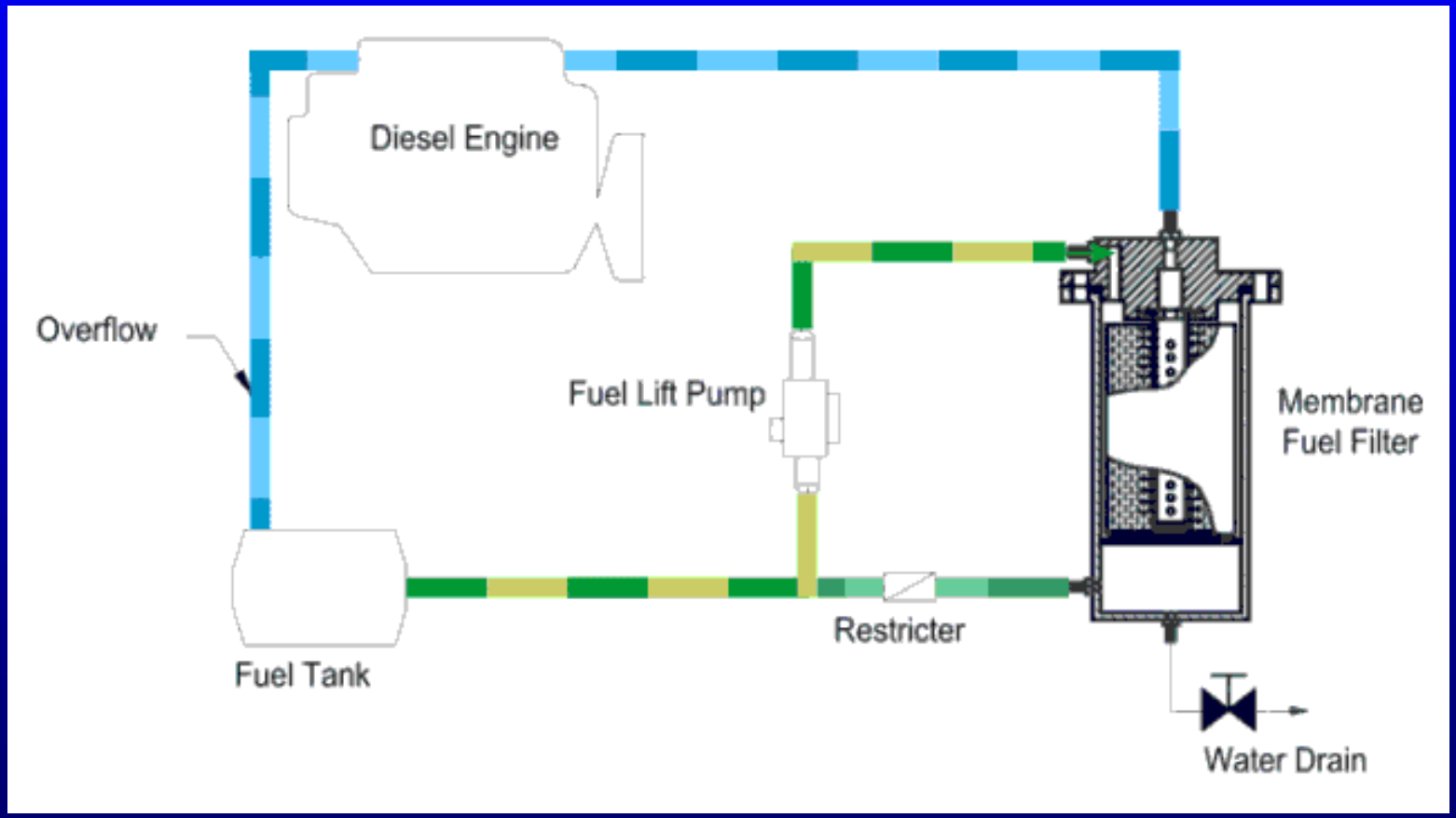
H1 Fuel Filter Element

H1 Fuel Filter Housing Design

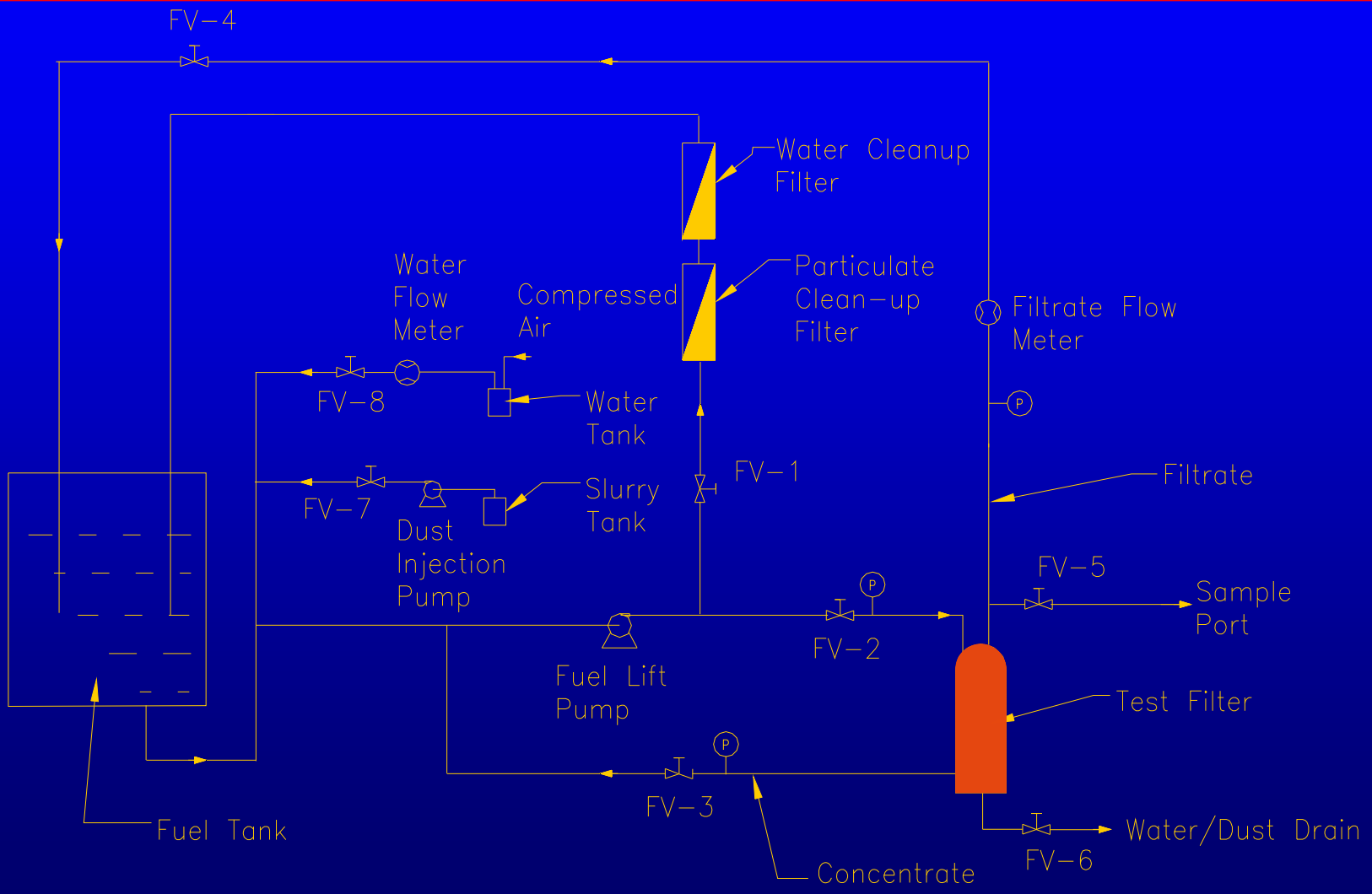


Membrane Filter Element in H1 Fuel Filter Housing

Membrane Fuel Filter System



Fuel Filter Test Setup



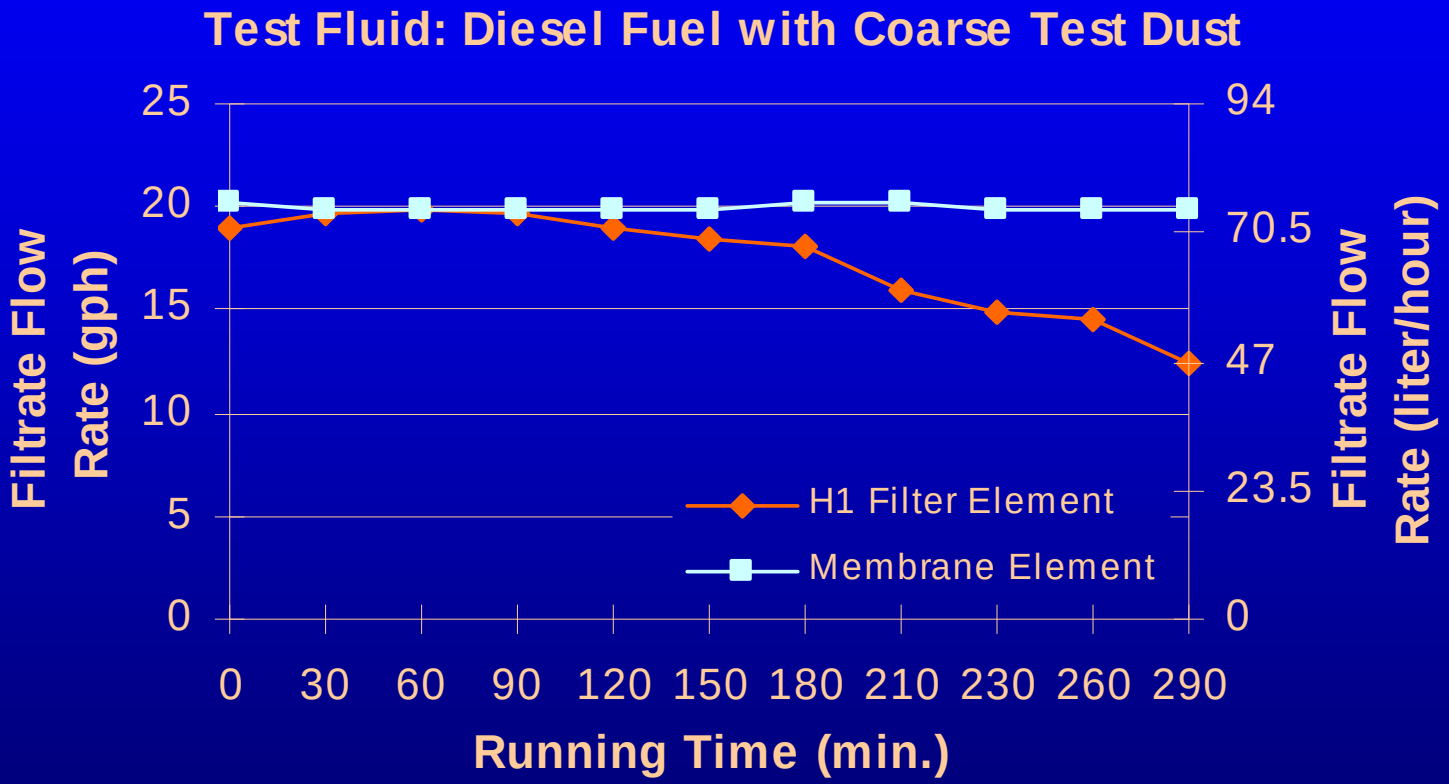
Test Materials and Methods

Test Fuel Filter Element Specifications:

	Element Dimensions	Measured Active Filter Medium Area
1 Micron Membrane Element	2.5” (6.35 cm) OD X 4” (10.16 cm) Long	2 ft^2 (44.6 cm^2)
2 micron H1 Fuel Filter Element	2.5” (6.35 cm) OD X 4.2” (10.67 cm) Long	2.2 ft^2 (49 cm^2)

1. Fuel: No.2 diesel fuel purchased from a commercial gas station
2. Test dust: ISO 12103-1, A4 coarse test dust
3. Water added into the fuel: unfiltered tap water
4. Water content measurement: Aqua-Glo Water Detector
5. Particle content measurement: PM4000 (HIAC) particle counter

Results of Dust Loading Capacity Test



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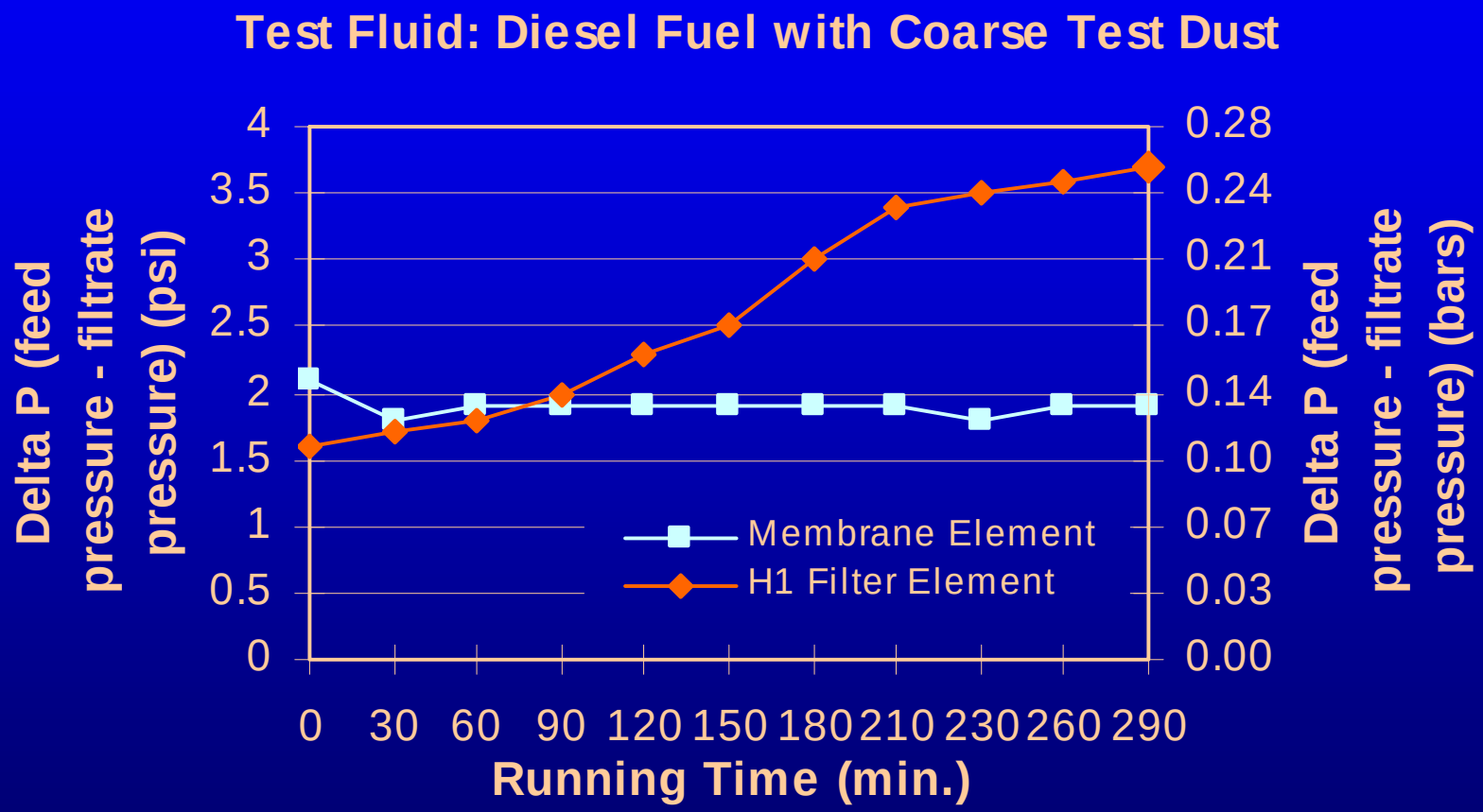

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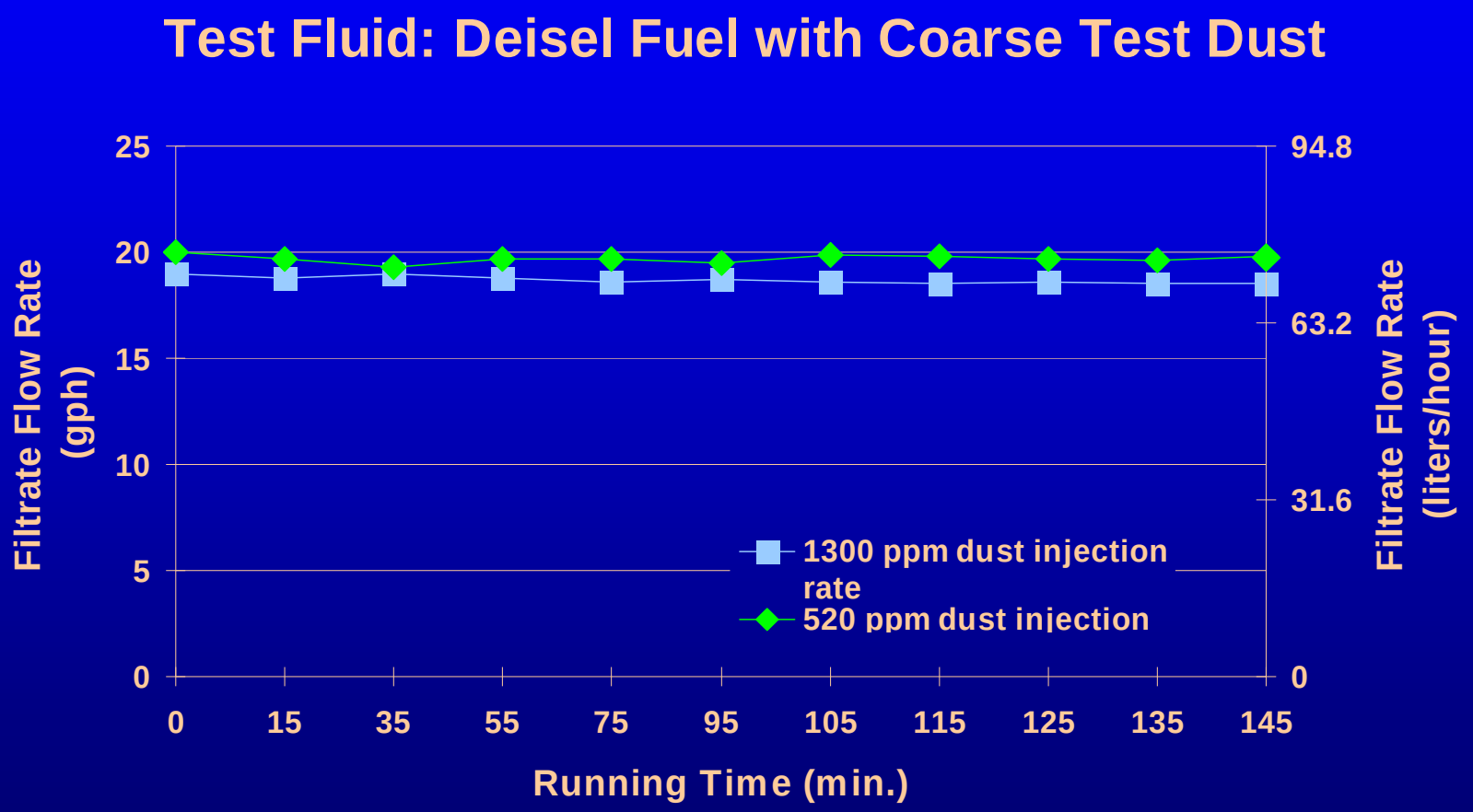


Results of Particle Removal Efficiency Test

Particle Count Test Results

Measured Sediment Particle Sizes in Filtered Fuel	4 Micron	6 Micron	14 Micron	21 Micron
Number of Particles Per Milliliter in Filtered Fuel from H1 Military Fuel Filter Element	4250	192	10	2.5
Number of Particles Per Milliliter in Filtered Fuel from 1 Micron Membrane Element	72	24	1.4	0.0

Results of Particle Removal Efficiency Test

BETA RATION AND PARTICLE REMOVAL EFFICIENCY

		4 Micron	6 Micron	14 Micron	21 Micron
H1 Current Fuel Filter Element	BETA Ratio	15	194.6	546.5	1071.8
	Particle Removal Efficiency	93.6%	99.5%	99.8%	99.9%
Membrane Fuel Filter Element	BETA Ratio	924	1556.5	3993.4	Infinity
	Particle Removal Efficiency	99.9%	99.9%	~ 100.0%	100.0%

Results of Water Removal Efficiency Test

	Water Content in Feed	0.1% Water	0.5% Water	1% Water	3% Water
H 1 Current Fuel Filter Element	Water Content in Filtrate	7 mg/L	About 100 mg/L	A lot of water was observed	A lot of water was observed
	Water Removal Efficiency	99.3%	98%		
Membrane Fuel Filter Element	Water Content in Filtrate	6.4 mg/L	9.0 mg/L	16 mg/L	26 mg/L
	Water Removal Efficiency	99.4%	99.8%	99.8%	99.9%

Comparisons of Filter Replacement Costs

Estimated Filter Replacement Costs

Fuel Filters	Retail Price	Parts Cost of Filter Element Replacement Over 6 Years	Labor Cost per Replacement	Total Cost of Filter Element Replacement Over 6 Years
H1 Military Fuel Filter Element	$7 [1]	$84 [3]	$15	$264
H1 Civilian Fuel Filter Element	$30 [2]	$360 [3]	$15	$540
Membrane Fuel Filter	$16.7	$50.1 [4]	$15	$95.1

1. Cost from TACOM.
2. Cost from Hummer distributor in NJ.
3. Two filter element replacements per year.
4. One filter element replacement per two years.

$ 8.5 Million per Year Cost Savings on Fuel Filter Element Replacement

* Based on 240,000 US military tactical wheeled vehicles and 60,000 combat vehicles (Year 2000).

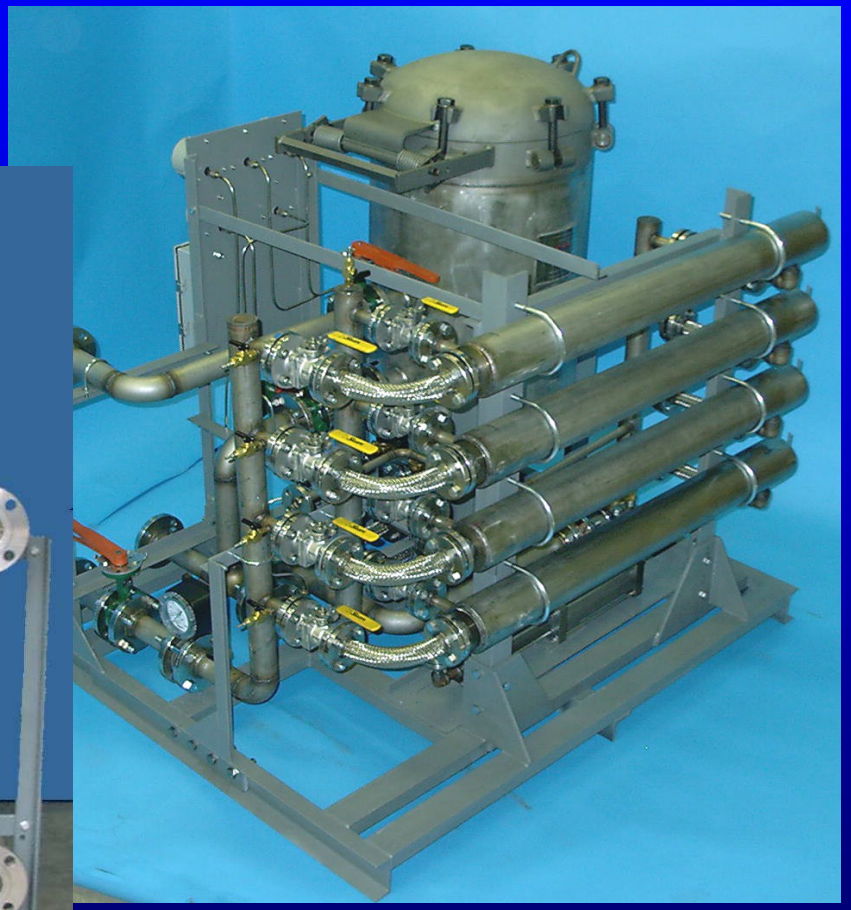
Conclusions and Discussions

- The dust loading capacity of the membrane filter element is approximately 5-10 times higher than the H1 filter element, indicating that the service life of the membrane fuel filter could be 5-10 times longer than the H1 military fuel filter.
- The particle removal efficiency of the membrane filter is about 98.3%, 87.5%, 86%, and 100% higher at the 4 micron, 6 micron, 14 micron, and 21 micron measured channels than the H1 fuel filter element.
- The membrane filter exhibits significantly higher water removal efficiency than the H1 filter at higher water concentrations (0.5%, 1% and 3%) in feed.
- The tested membrane element can meet the fuel flow output requirement of 16.5 gph at high water and high debris concentration conditions
- The 16.5 gph membrane fuel filter element can be designed to fit into the current H1 military fuel filter housing.
- The membrane fuel filter can reduce the fuel filter replacement cost about $8.5 millions per year to U.S. military.

Potential Commercial Applications

1. Automobile Fuel Filtration
2. Marine Fuel Filtration
3. Aviation fuel filtration
4. Refinery hydrocarbon product filtration
5. Oil Filtration

Diesel Fuel Filter for U.S. Navy DDG Class Ships



U.S. Navy
Aviation Fuel Filter

U.S. Army Aviation Fuel Filter

Canadian Army Diesel & Gasoline Fuel Filter

Commercial Fuel/Oil Filtration System